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NESTING RANGE, SPATIAL USE, HABITAT SELECTION AND SEX IDENTIFICATION OF THE GREATER ROADRUNNER (*Geococcyx californianus*)

A Thesis

by

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Texas A&M University
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MASTER OF SCIENCE

Approved by:

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ABSTRACT

I conducted this study to better understand the greater roadrunner's (*Geococcyx californianus*) spatial use, nest site selection, and sexual morphometrics. Data were first collected from a roadrunner population in Fisher County, Texas. I trapped, measured, and removed feathers for sex confirmation through DNA PCR analysis. I then fit the roadrunners with a radio transmitter and released them at the capture site.

I captured a total of 10 birds (1 male and 9 females) and triangulated the location of each bird 2-4 times per week from February to August 2011 during the roadrunner nesting season. The data produced a mean minimum convex polygon nesting range of 43.01-ha, a 50% core utilization distributions of 11.88-ha, and an overlap index of 33.05 percent. Habitat selection ratios showed a preference for ridge as well as grassland habitat and avoidance of bare ground and flatland habitats.

The location data from west Texas was further analyzed to build a predictive logistic regression model to understand the significant site characteristics in roadrunner land use during the nesting season. It was determined that percent rock (-0.12, P = 0.0001) and percent litter (-0.05, P = 0.0052) were the best predictors in determining actual from random locations. Rock references open area for hunting, transportation as well as ridge habitat. Litter alludes to region below dense stands of shrubs and is used by roadrunners for evasion from threats and as shade for thermoregulation.

The measurements from the roadrunners in west Texas as well as museum specimens from across their natural range were combined to develop an easy,

inexpensive, and field-relevant sex identification model. The strongest model consisted of bill depth (0.79, $P< 0.0001$) and bill tip to the back of the head (0.05, $P = 0.1573$) which were both found to be larger in males.

The final portion of this study concerned roadrunner nest site selection. Data were collected in Wilbarger County, Texas from May 2006 to October 2009. A predictive logistic regression model of nesting locations determined that mesquite nesting tree (-0.89, $P = 0.0064$), oval tree shape (1.58, $P = 0.0118$), mesquite density (-0.004, $P = 0.0080$), and topographic edge (1.37, $P = 0.0027$) were the best predictors in determining actual nest sites from random locations.

DEDICATION

Dedicado a mi familia.

ACKNOWLEDGEMENTS

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Finally, I would like to thank the following people and museums for their help and use of their collections: Mayborn Museum at Baylor University, the Texas Cooperative Wildlife Collections at Texas A&M University, Sam Houston State University Vertebrate Museum, the Natural Science Research Laboratory at Texas Tech University Museum, the natural history collections at Angelo State University, the Rob and Bessie Welder Wildlife Foundation, the Sam Noble Museum at the University of Oklahoma, Christopher Witt and the Museum of Southwestern Biology at the University of New Mexico, Patricia Gegick and the New Mexico Museum of Natural History & Science, Christopher Milensky and Mercedes Foster at the Smithsonian Institution National Museum of Natural History, and the Museum of Vertebrate Zoology at the University of California, Berkeley.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

The greater roadrunner (*Geococcyx californianus*; here after roadrunner) is a member of the cuckoo family found in the semi-arid and arid regions of the southwest. The roadrunner's range extends longitudinally from California to Arkansas and encompasses latitudes from southern Kansas to central Mexico (Meinzer 1993, Maxon 2005, Payne et al. 2005). Roadrunners are non-migratory residents with home ranges and territories that appear to be stable between years (Folse 1974, Hughes 1996, Maxon 2005). Generally, roadrunners occur in open areas of grassland or bare ground in close proximity to dense shrubs and trees. These two distinct zones are thought to be important for foraging as well as protection from heat and predation. Accordingly, desert scrub, chaparral, savanna, open brush, open woodlands, and wooded stream corridors are their most recognized habitat types (Maxon 2005).

To date, roadrunners have been inadequately studied. Existing literature on spatial use and population demographics can be split into two general categories based on methodology. The initial studies utilized opportunistic re-sightings of marked birds (Bryant 1916, Calder and Schmidt Nielsen 1967, Folse 1974) and appear to underestimate ecological parameters (e.g., home range, habitat use) as estimates were dependent upon the researcher's ability to locate the bird. Newer studies have utilized radio-telemetric techniques (Vehrencamp 1982 [focused solely on temperature regulation], Kelley et al. 2011) that allow researchers to quantify activity and

demographic attributes that may be periodically out of the observer's sight. This is especially important given the cautious nature and evasive behavior of roadrunners (Folse and Arnold 1978, Vehrencamp and Halpenny 1981, Bolger et al. 1991, Kelley et al. 2011).

Other aspects of roadrunners, such as sexual morphology, are only partially explored in literature. Accurate sexual identification of individuals is important in understanding common questions of population ecology including sex ratios in a breeding population, differential mortality, behavioral studies (e.g., male/female incubation behavior), differential habitat selection, and sex specific demographics (Iko et al. 2004, Gill and Vonhof 2006, Wallace et al. 2008). These topics are difficult to study with roadrunners given their sexually monomorphic plumage. Previous studies have successfully sexed roadrunners using copulatory behavior (Whitson 1976), dissection (Ohmart 1973), and PCR-based DNA analysis (Santamaria et al. 2010) but have failed in describing an easy, unambiguous, and non-invasive method to identify sex in the hand at the point of capture. Folse and Arnold (1978) described a sexing technique using post-orbital apterium coloration, but this was found to be unreliable (Meinzer 1993, Kelley et al. 2011).

Entirely absent from literature are studies of resource and nest site selection (Maxon 2005). Literature only describes nest tree species and the nest height (Ohmart 1973, Folse 1974, Meinzer 1993, Hughes 1996, Maxon 2005, Payne et al. 2005). Because nest site characteristics can influence the nest success and number of fledged young (Martin and Roper 1988), understanding nest site selection is critically important

to the maintenance and reproductive success of the species (Filliater et al. 1994, Maxon 2005). This understanding can then be used to insure proper management and preservation (Gregg et al. 1994, DeLong et al. 1995, Kolada et al. 2009).

My goal in this study was to further contribute to the understanding of roadrunner ecology by addressing the following four areas. I first quantified the roadrunner nesting range, degree of heterogeneity, percent overlap, and habitat use during the nesting season. I next analyzed point locations to better understand the role of topographic and vegetative features in roadrunner habitat selection. I then evaluated morphological characteristics (e.g., tarsus length, bill width, etc.) as a means of distinguishing male and female roadrunners. Finally, I assessed roadrunner nesting sites in an attempt to understand significant habitat characteristics.

Research in the ecology and needs of the roadrunner and other birds in this region is especially important given projections of widespread grassland bird declines (Brennan and Kuvlesky 2005). Recent figures report 39% of arid land birds, in particular, are of conservation concern and more than 75% are declining (US Department of Interior 2011). It is my intention that this research be used to more effectively manage roadrunner populations and stimulate further investigation.

CHAPTER II

NESTING RANGE ECOLOGY AND HABITAT SELECTION IN WEST TEXAS

Introduction

The greater roadrunner (*Geococcyx californianus*; here after roadrunner) has been inadequately studied. Existing literature on spatial use and population demographics can be split into two groups based on methodology. The preliminary studies utilized opportunistic re-sightings of marked birds (Bryant 1916, Calder and Schmidt Nielsen 1967, Folse 1974) and appear to underestimate ecological parameters (e.g., home range, habitat use) as estimates were dependent upon the researcher's ability to locate the bird. More recent studies have utilized radio-telemetric techniques (Vehrencamp 1982 [focused solely on temperature regulation], Kelley et al. 2011) giving researchers the ability to quantify activity and demographic attributes out of the observer's sight. This is especially critical because of the cautious nature and evasive behavior of roadrunners (Folse and Arnold 1978, Vehrencamp and Halpenny 1981, Bolger et al. 1991, Kelley et al. 2011).

With this study I hope to better understand roadrunner nesting range size, percent overlap, and habitat use as compared to similar parameters described in literature. The nesting season can be especially critical in the maintenance of a population (Martin and Roper 1988) and the ecology of the roadrunner has yet to be studied in this region of Texas.

Methods

Data were collected from February to August 2011 on the 1902-ha Rolling Plains Quail Research Ranch (32°02'16" N, 100° 32' 50" E) in the Rolling Plains ecological region (Gould 1975) of west Texas approximately 16-km west of Roby, Texas in Fisher County. The site contained substantial ridge habitat ranging in height from 15 to 35 meters and ranging in slope from 5 – 50 percent. Ridge soils contained patches of Travessilla and Vernon soil series. Travessilla soil series are characterized by shallow gravelly soils over conglomerate rock or sandstone that is gently to steeply sloping or rough and broken. Vernon soil series have shallow reddish brown soils with gently to strongly sloping with many quartzitic pebbles on the surface (USGS 1972).

The ranch contained pockets of mixed grass prairie, Conservation Reserve Program (CRP) fields, food plots, and dense stands of honey mesquite (*Prosopis glandulosa*), shinnery oak (*Quercus havardii*), and red-berry juniper (*Juniperus pinchotii*). Ridge slopes were characterized by large dense mottes of shrubs while ridge tops supported small, sparse patches of shrubs and mixed grasses.

Land management practices included prescribed burns, mechanical shrub control, as well as aerial and ground herbicide sprays. Land development on the study site consisted of gravel and dirt roads, barbed wire fences, water troughs, and electrical poles. The surrounding private land uses include natural pastures, CRP fields and cotton fields fallow after harvest.

I captured roadrunners using three methods. The first method was a modified bal-chatri trap (Berger and Mueller 1959, Lake et al. 2002, Vilella and Hengstenberg 2006)

that consisted of a caged mouse (*Mus musculus*) surrounded by monofilament nooses on plywood boards that were nailed into the ground. These adjustments were implemented to address the roadrunner's unique ground-level hunting style (Kelley et al. 2011). The second technique was a box trap with a caged mouse in the back as bait (Vehrencamp and Halpenny 1981, Bub 1991, Kelley et al. 2011). Finally, a small number of birds were successfully hand captured in the field. These birds were newly fledged juveniles or adults cornered by a fence or dense shrub.

Roadrunners were measured with the help of a field assistant who restrained the bird by grasping its torso and holding down the wings. I measured the roadrunners for mass, tarsus length, bill depth, bill width, bill tip to nearest dorsal feathers, bill tip to base of bill, bill tip to commissure, bill tip to nostril, and bill tip to the back of the head to the nearest 0.1-mm or 1-g, as appropriate . Both the bill width and bill depth were measured at the leading edge of the nostril. I then removed downy feathers for sex verification through PCR DNA analysis following the methods of Santamaria et al. (2010). Finally, birds were fitted with a 10-g back-pack style radio-transmitter and immediately released at the capture site without any apparent changes in behavior.

I relocated roadrunners 2-4 times/ wk via triangulation of compass bearings from 3-5 positions. Locations were calculated with the program LOCATE III (Nams 2006) utilizing the maximum likelihood estimator and estimated standard deviation settings. I considered a location to be acceptable when the location error ellipse was less than 1-ha. This was used as a threshold from which to gauge the strength of a triangulation (Saltz and Alkon 1985). When triangulation errors are large compared to habitat patch size,

precision suffers and bias is introduced as there is an increased likelihood of type II error when determining habitat preference (White and Garrott 1986, Nams 1989, Saltz 1994). Visual observations of marked roadrunners obtained during field work were recorded with a handheld GPS and the resultant coordinates were included in the nesting range estimation.

Statistical tests for nesting range and overlap index followed after the methodology used by the Kelley et al. (2011) roadrunner study in north central Texas. I calculated 95% Minimum Convex Polygons (MCP) with the program Home Range Tools for ArcGIS with the fixed mean selection style (Rodgers 2007). Comparison between male and female mean MCP was then analyzed with a Wilcoxon signed ranked test. I also calculated the Kernel Distribution Estimator's (KDE) 95% nesting range and 50% core utilization distribution isopleths using Home Range Tools for those birds with more than 30 locations (Rodgers 2007, Kelley et al. 2011). Calculation settings included a fixed kernel estimator and least-square cross-validation to estimate the smoothing parameter. Kernel density estimator nesting range and core areas were also calculated for those animals with less than 30 locations for comparison with the previously calculated confidence interval.

I calculated overlap index with the MCPs which do not traditionally limit individuals because of insufficient number of relocations and was therefore more inclusive. I found the overlapping areas of nesting range MCPs using the interest tool in ArcMap (ESRI 2009) and the overlap index was then calculated using the formula $OI = [(n_1 + n_2) / (N_1 + N_2)] \times 100$. Here n_1 and n_2 are the number of the adjacent individuals'

locations within the overlap polygon and N_1 and N_2 corresponded to the total number of locations for the two roadrunners used in the calculation of the nesting range (Chamberlain and Leopold 2002, Brunjes et al. 2009, Kelley et al. 2011). Overlap indices with a value of zero were not included.

For this study I defined habitats as areas of unique vegetative cover types or topographic features where roadrunners were found. Vegetative habitats included shrub, dense grass, sparse grass, and bare ground while topographic habitats included flats and ridge. ArcMap (ESRI 2009) was used to determine the proportion of each habitat type in the study area. With this information I determined the roadrunner habitat use with resource-selection ratios (e.g. selection functions; Manly et al. 2000). Researchers have found selection ratios a more helpful description of habitat use (Lopez et al. 2004, McCleery et al. 2007, Kelley et al. 2011) given the *a priori* knowledge of non-random habitat use (Cherry 1998, Johnson 1999).

I calculated habitat selection ratios with the formula $S = ([U + 0.001] / [A + 0.001])$ where U and A correspond to observed use and availability (McCleery et al. 2007) and 0.001 is added to insure non-zero numbers (Bingham and Brennan 2004). Observed use was determined to be the number of locations for each vegetation type. Availability was the number of locations for each roadrunner multiplied by the proportion of each habitat type in the study area (Aebischer et al. 1993).

I looked at first, second, and third order spatial scales of habitat selection ratios (Johnson 1980). First order selection ratios were first calculated by comparing the proportion of locations in each habitat type to the proportion of each habitat type in the

study area. Second order selection ratios compared locations within the 95% MCP nesting range estimates of all birds calculated as a collective, to habitat types in the study area. Finally, third order selection ratios were found by comparing the proportion of locations in each habitat type to those present in their individual 95% MCP nesting range estimate. Selection ratios were calculated with means and 95% confidence intervals. Selection ratios (S) = 1.0 indicated resource use proportional to availability. A selection ratio >1.0 was interpreted as habitat preference while a selection ratio <1.0, indicates avoidance (Manly et al. 2000).

One vegetative and one topographic map were used for this analysis. I created the vegetative map using ArcMap's unsupervised image classification (ESRI 2009) with four classes or habitats. These were described as shrubs, dense grass, sparse grass, and bare ground/rock. Four classes were determined to be most appropriate because it lack redundancies and had the clearest delineations. The topographic map split the study area into flats and ridge. The ridge category included the ridge top, incline, and a 25-m buffer along the ridge base.

All data analysis was performed using JMP 9 (SAS Institute2007) and ArcGIS 9.3.1(ESRI 2009) with a significance level of $\alpha = 0.05$.

Results

Ten roadrunners (1 male, 9 females) were caught over the course of the study. These roadrunners were relocated a total of 437 times excluding the two relocations with

Table 1. First-order habitat selection for greater roadrunners in Fisher County, Texas.

Habitat	$\bar{x}$	Median	Confidence Interval	Outcome
Shrubs	0.7746	0.7063	0.44, 1.11	Proportional
Dense Grass	2.9499	2.5162	1.70, 4.20	Preferred
Sparse Grass	2.2545	2.0594	1.76, 2.74	Preferred
Bare Ground	0.1476	0.1342	0.07, 0.23	Avoided
Flats	0.4459	0.4194	0.20, 0.69	Avoided
Ridge	3.0303	3.4909	1.49, 4.57	Preferred

Table 2. Second-order habitat selection for greater roadrunners in Fisher County, Texas.

Habitat	$\bar{x}$	Median	Confidence Interval	Outcome
Shrubs	0.7758	0.8446	0.44, 1.12	Proportional
Dense Grass	3.1089	3.0911	2.55, 3.67	Preferred
Sparse Grass	2.4523	2.2186	1.96, 2.95	Preferred
Bare Ground	0.2452	0.2146	0.16, 0.33	Avoided
Flats	0.5302	0.4848	0.21, 0.85	Avoided
Ridge	3.1757	3.3825	1.71, 4.64	Preferred

Table 3. Third-order habitat selection for greater roadrunners in Fisher County, Texas.

Habitat	$\bar{x}$	Median	Confidence Interval	Outcome
Shrubs	1.1267	0.9879	0.74, 1.52	Proportional
Dense Grass	1.0532	0.9454	0.61, 1.50	Proportional
Sparse Grass	1.0623	0.9664	0.82, 1.30	Proportional
Bare Ground	0.8544	0.6418	0.15, 1.56	Proportional
Flats	1.1920	0.9000	0.42, 1.96	Proportional
Ridge	0.8952	1.0712	0.53, 1.26	Proportional

the largest triangulation error polygons. The average error polygon was 0.644-ha (CI = 0.237, 1.050).

Mean MCP and KDE nesting range was 47.4-ha (CI = 23.1, 71.6) and 91.6-ha (CI = 36.7, 146.5), respectively. Mean KDE core estimate was 21.1-ha (CI = 8.3, 33.9). We then included all roadrunners in the kernel estimate despite fewer locations than suggested in literature (Rodgers 2007, Kelley et al. 2011). The pooled KDE was 70.8-ha (CI = 40.6, 100.9). None of the above nesting range estimates were significantly different (T = 13.5, P = 0.1289).

The nesting range overlap index was split into two groups: one index that included all overlapping polygons regardless of time and one index of only overlapping polygons concurrently used by birds. The average overlap index for the pooled overlap polygons was 33.05% (CI = 20.22, 45.88%) while the polygons of only concurrent birds averaged 34.95% (CI = 16.48, 53.43%). A t-test showed these two overlap indices to not be significantly different (t = -0.5774; P = 0.5946).

Habitat Selection preference values are described in Table 1, 2, and 3.

Discussion

My nesting range estimates were similar to range estimates reported by earlier observational studies (range 28-50 ha; Bryant 1916, Calder and Schmidt Nielsen 1967, Folse 1974) and approximately half the size of those reported by Kelley et al. 2011. Home range size (and as a result nesting range size) is thought to be a function of resource availability increasing in size as the abundance and availability of resources declines (Ford 1983). In addition to distribution of resources, there are a few possible

explanations within this context that may explain the differences between my study and that of Kelley et al. (2011).

First, a large part of the variability lies in that this study was conducted within one nesting season while Kelley et al.'s study spanned 4 years. Also, the two study sites differed in resource distribution and topography in that the Kelley et al. (2011) site was highly fragmented and contained no ridges which offer additional area in their slopes. Studies using mapping software to account for topographic complexity found home range estimates ranged 3 to 14% larger than two-dimensional, planimetric home range estimates (Stone et al. 1997, Castleberry et al. 2001, Campbell et al. 2004, Greenberg and McClintock 2008).

Ridge habitat was important to roadrunners in this area and was used for a variety of functions. Dense groups of shrubs found on ridges were used for roosting sites, and escape from predators. When encountered near a ridge, roadrunners often ran up the ridge to a rocky summit or into a dense motte of shrubs. These areas are also hunting grounds for small lizards and snakes sunning on the rock or mammals that burrow around shrubs and in the ridge crevices. The ridge also offered significant exposure to prevailing winds and their concentration of shrubs provide shade for thermal regulation.

This is especially noteworthy given the collection of my data coincided with one of the worst recorded droughts in Texas history (Walsh et al. 2011).Average monthly temperatures registered up to 4 °F higher and precipitation for this period was only 6.4-cm compared to the area's 5 year average of 29.85-cm (NOAA 2011). Previous studies

have hypothesized that the stress of the drought likely affects both the nesting range and behavior of roadrunners as resources become scarce (Ford 1983). The scope of this study makes quantifying the effect of the drought with these data difficult but it is worth noting that precipitation during the Vernon study was also well below yearly averages (NOAA 2011).

While there may be inherent differences between populations, the lack of older studies with consistent methodologies makes this conclusion only speculative. It is worth noting that the confidence interval associated with my nesting range mean was large enough that the Vernon study's mean was not significantly different. Additionally, there was no significant difference between the more traditional KDE calculations for birds with at least 30 locations as those with fewer therefore suggesting that 30 locations was not necessarily indicative of the minimum number of roadrunner locations necessary for KDE calculations. It is difficult to draw concrete conclusions from the KDE calculations because of the large variation associated with this study's small sample size.

The Vernon, Texas study overlap index of 38.4% (Kelley et al. 2011) was not significantly different from this study (t = -0.901, P = 0.3841) further demonstrating the roadrunner's less exclusive use of habitat (Folse 1974, Meinzer 1993, Maxon 2005). Female specific overlap index of the Vernon's study was lower than this study at 20% and likely was from Vernon's scarcity of the preferred riparian habitat (Kelley et al. 2011). This study site's habitat selection calculations showed no preference to a scarce habitat resulting in a larger overlap index. Fifty percent core estimates were also not significantly different (t = -1.1752, P = 0.3247). Maintenance of the core 50% utilization

distribution could underlie the greater importance of a core area for the acquisition of resources such as food, water, and shelter.

The results of this study also differ from the Vernon study in that roadrunners were not found to prefer habitats with shrubs but rather grasslands (Kelley et al. 2011) as reported in older, sight-based tracking (Folse 1974). This difference is likely an artifact of the methods used in defining habitats. The aerial image used to classify the vegetation map for this study contained enough detail to allow for the classification of grassland habitat between individual shrubs therefore producing results at finer scale.

The roadrunner's avoidance of bare ground may be a strategy to evade detection by predators. In turn, the preference of ridge habitat and avoidance of flats gives roadrunners the advantage over prey when used as an elevated perch. Habitat selection ratios were similar to the Vernon study in their selection of resources related to vegetative cover and topography at a course grained scale. This suggests that necessary resources are uniformly available within their nesting range (Wiens 1976).

Additional comparisons of home range metrics with similar taxa are difficult given the roadrunner's unique lifestyle. The lesser roadrunner (*Geococcyx velox*) is the closest species taxonomically but has even less published research.

Management Implications

Despite similar methodologies with the Vernon study (Kelley et al. 2011), there were still inconsistencies in range size estimates and habitat selection preferences. My data reveals the uniqueness of this populations use and interaction with the environment. Ridges appear to be especially important given its potential use for roosting sites, escape

from predators, hunting habitat, and thermal regulation. With this population it is important that the distinctive ridge topography and nearby plant communities are maintained and managed to insure preservation.

CHAPTER III

POINT LOCATION PREDICTION MODEL

Introduction

Little is known of the greater roadrunner's (*Geococcyx californianus*; here after roadrunner) habitat preferences. Previous studies simply describe the vegetation and geography of the study site (Ohmart 1973, Folse 1974, Meinzer 1993, Hughes 1996, Maxon 2005, Payne et al. 2005, Kelley et al. 2011). A greater understanding of roadrunner habitat use is especially important in this region of Texas given the increase in land clearing for domestic grazers, exploratory drilling, and wind farms.

With the use of telemetry location data, I hoped to better understand the combination and magnitude of different geographic and vegetative features in a roadrunner's habitat during the spring and summer nesting season. This information can then help predict or restore suitable habitat for more effective management and conservation.

Methods

Data were collected from February to August 2011 on the 1902-ha Rolling Plains Quail Research Ranch (32°02'16" N, 100° 32' 50" E) in the Rolling Plains ecological region (Gould 1975) of west Texas approximately 16-km west of Roby, Texas in Fisher County. The site contained substantial ridge habitat ranging in height from 15 to 35 meters and ranging in slope from 5 – 50 percent. Ridge soils contained patches of Travessilla and Vernon soil series. Travessilla soil series are characterized by shallow

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Land management practices included prescribed burns, mechanical shrub control, as well as aerial and ground herbicide sprays. Anthropogenic land development on the study site consisted of gravel and dirt roads, barbed wire fences, water troughs, and electrical poles. The surrounding private land uses included natural pastures, CRP fields and cotton fields left fallow after harvest.

I captured roadrunners using three methods. The first method was a modified bal-chatri trap (Berger and Mueller 1959, Lake et al. 2002, Vilella and Hengstenberg 2006) that consisted of a caged mouse (*Mus musculus*) surrounded by monofilament nooses on plywood boards that were nailed into the ground. These adjustments were implemented to address the roadrunner's unique ground-level hunting style (Kelley et al. 2011). The second technique was a traditional box trap with a caged mouse as bait (Vehrencamp and Halpenny 1981, Bub 1991, Kelley et al. 2011). Finally, a small number of birds were successfully hand captured in the field. These birds were newly fledged juveniles or adults cornered by a fence or dense shrub.

Roadrunners were measured with the help of a field assistant who restrained the bird by grasping its torso and holding down the wings. I then measured the roadrunners for mass, tarsus length, bill depth, bill width, bill tip to nearest dorsal feathers, bill tip to base of bill, bill tip to commissure, bill tip to nostril, and bill tip to the back of the head to the nearest 0.1-mm or 1-g, as appropriate. Both the bill width and bill depth were measured at the leading edge of the nostril. I then removed downy feathers for sex verification through PCR DNA analysis following the methods of Santamaria et al. (2010). Finally, birds were fitted with a 10-g back-pack style radio-transmitter and immediately released at the capture site without any apparent changes in behavior.

I relocated roadrunners 2-4 times per week via triangulation of compass bearings from 3-5 distant positions. Locations were calculated with the program LOCATE III (Nams 2006) utilizing the maximum likelihood estimator and estimated standard deviation settings. I considered a location to be acceptable when the location error ellipse was less than 1-ha. This was used as a threshold from which to gauge the strength of a triangulation (Saltz and Alkon 1985). When triangulation errors are large compared to habitat patch size, precision suffers and bias is introduced as there is an increased likelihood of type II error when determining habitat preference (White and Garrott 1986, Nams 1989, Saltz 1994). Visual observations of marked roadrunners obtained during field work were recorded with a handheld GPS and the resultant coordinates were included in the nesting range estimation.

To construct the model 30 triangulated roadrunner locations were randomly selected along with 30 locations found using ArcMap's random location generator (ESRI

2009). Random locations were stratified to consider only the portions of the ranch in which roadrunners were known to inhabit. At a location a 10-m line intercept was used along the 4 compass directions (Kopp et al. 1998) to estimate brush canopy cover (Canfield 1941). Brush density was calculated within a 10-m radius of the location by dividing the total number of shrubs by the area sampled (Density = $n/2\pi[10]^2$). A Robel pole (Robel et al. 1970) estimated visual obstruction as well as the disc of vulnerability. The disc of vulnerability is the distance at which specified strata on the Robel pole is totally obscured (Kopp et al. 1998). This information is related to the distance in which a roadrunner might be visible to ground dwelling predators such as bobcats (*Lynx rufus*) or coyotes (*Canis latrans*). It was originally developed for northern bobwhites (*Colinus virginianus*) on south Texas rangelands utilizing the first decimeter as the strata of interest. For roadrunners, which stand approximately 30-cm high, I used the area of the Robel pole comprising the first 3 decimeters and measured distance with an electronic range finder.

I then used a 20 x 50-cm sampling frame at 5 points (2, 4, 6, 8, and 10-m) along 4 line transects in the compass directions to visually estimate percent grass, forb, litter, rock, and bare ground exposure. Finally, the nearest edge type was recorded (e.g. game trail, road, ridge, brush line, contour, and disked strip). All vegetative measurements were repeated in the same manner at both triangulated and random locations (Ransom et al. 2008).

I calculated means and 95% confidence intervals (CI) for all habitat variables and tested the data for normal distribution. Differences in random and telemetry locations

means were then determined using parametric two sample t-test or non-parametric Wilcoxon signed ranked according to the results of normality testing (Ransom et al. 2008). A nominal logistic regression model was then developed to try to correctly classify a location as random (model =0) or true location (model =1).

Regression analysis was run on full, reduced, and constant only models and the strongest model was chosen based on the goodness-of-fit test, lack of fit test, AICc, R^2, and the area under the receiver operating characteristics curve (AUC). Once a model was considered, I tested the variables for interactions with a pair-wise Pearson correlation analysis. Pairs of variables that were found to be highly correlated had one variable removed before any further analysis. Odds ratios for the variables in the chosen model were reported with their confidence intervals.

Another 30 telemetry locations and 30 random locations were found in the same manner as above and the variables of the chosen model were again measured to cross-validate the hypothesized model. The results for the validation model's goodness-of-fit, lack of fit, AUC, and odds ratio were reported. All statistical tests were performed at $\alpha = 0.05$ with JMP 9 (SAS Institute 2007).

Results

Ten roadrunners (1 male, 9 females) were trapped over the course of the study. I relocated birds a total of 437 times excluding two relocations with the largest triangulation error polygons. Of the 437 relocations, the average error polygon was 0.644 ha (CI = 0.237, 1.050 ha).

The statistics for continuous variables measured at both random and actual point locations and the results of their corresponding comparison of means tests are summarized in Table 4. The statistics for the categorical data measured at both random and actual point locations sites and their corresponding results from differences in proportions testing are summarized in Table 5.

With a sample size of 60 (30 actual and 30 random), the best fitting and logistic model contained percent rock (R; $P = 0.0001$), percent litter (L; $P = 0.0052$), and intercept ($P = 0.0006$).

$$(S) = 3.36 - 0.12R - 0.05L$$

Statistical tests showed the whole model to be significant ($\chi^2 = 31.08$, $P < 0.0001$) with no lack of fit ($\chi^2 = 52.10$, $P = 0.6591$) and an AUC of 0.88. The odds ratio of actual versus random locations for rock was 1912.524 (CI = 64.24, 178609.6) and litter was 64.478 (CI = 4.256, 1603.542). Litter and Rock were not found to be significantly correlated ($\rho = -0.0966$, $P = 0.4626$).

Model validation with an addition 30 random and confirmed locations similarly found rock (0.10, $P < 0.0001$), litter (0.04, $P = 0.0003$), as well as the intercept (-2.9, $P < 0.0001$) to be significant. There was no lack of fit ($\chi^2 = 120.82$, $P = 0.3611$), the whole model test was significant ($\chi^2 = 42.77$, $P < 0.0001$), and the AUC measured 0.83. The odds ratio of rock was 495.13 (CI = 47.375, 8130.858) and litter was 57.40 (CI = 7.083, 597.578) for actual locations versus random locations.

Table 4. T-test and Wilcoxon signed ranked test results of random versus triangulated point location means.

Variable	Random mean (CI)	Nest site mean (CI)	t-test	Wilcoxon Signed Rank
Distance to edge	16.18 (8.02, 24.34)	8.01 (4.55, 11.50)		$T = 67.5$, $P = 0.0498$
Visual Obstruction	1.10 (0.71, 1.49)	1.23 (0.73, 1.72)		$T = -103.5$, $P = 0.0306$
Disc of Vulnerability	27.27 (20.06, 34.48)	18.73 (15.72, 21.73)		$T = 111.5$, $P = 0.0190$
Brush CC	0.10 (0.04, 0.15)	0.29 (0.21, 0.36)		$T = -213.5$, $P < 0.0001$
Brush Density	0.13 (0.10, 0.17)	0.16 (0.13, 0.18)		$T = -77.5$, $P = 0.1116$
Percent Bare Ground	30.25 (22.13, 38.37)	13.76 (8.81, 18.71)		$T = 165.5$, $P = 0.0002$
Percent Rock	4.16 (1.34, 6.97)	21.88 (15.02, 28.73)		$T = -228.5$, $P < 0.0001$
Percent Litter	32.04 (24.95, 39.13)	42.13 (34.60, 49.67)	$t = -2.9107$, $P = 0.0069$	
Percent Grass	31.79 (23.33, 40.25)	21.23 (16.78, 25.68)		$T = 96.5$, $P = 0.0451$
Percent Forbs	1.94 (1.03, 2.85)	0.63 (-0.14, 1.39)		$T = 101.0$, $P = 0.0344$

Table 5. Comparison of mean vegetative characteristics at greater roadrunner point and random sites in west, Texas.

Variable	Random	Actual	Pearson's χ^2
Ridge	0.13	0.70	χ^2= 45.87, $P < 0.0001$
Edge Type			
Road	0.53	0.13	χ^2 = 0.53, $P < 0.0001$
Game Trails	0.17	0.47	χ^2 = 10.85, $P = 0.0010$
Ridge	0.03	0.27	χ^2 = 8.35, $P = 0.0039$
Creek [A]	0.00	0.10	
Brush Line [A]	0.00	0.03	
Contour [A]	0.20	0.00	
Disk Strip [A]	0.07	0.00	

[A] Low occurrence at random and actual sites makes probability testing unreliable

Discussion

The data used to build this model was collected from mostly females and the results may have differed with the inclusion of additional males. The model and validation statistics were both strong and lend credibility for use of the model in this area. Both the model and resulting odds ratios emphasize the importance of rock and litter in actual roadrunner locations. Both variables allude to the importance of ridge top and ridge slope where most roadrunners were spotted during the course of the study.

Litter was mainly measured below dense mottes of shrubs on the ridge slope and top. Shrubs are known roadrunner nesting substrate (Ohmart 1973, Folse 1974, Meinzer 1993, Hughes 1996, Maxon 2005, Payne et al. 2005) and appeared to offer escape and security from predators or perceived threats. Nearly all roadrunners encountered on this site were near or on a ridge and when met during the course of field work would immediately run to the nearest dense shrubs.

During warm weather, shrubs on the ridge also offer exposure to prevailing winds and one of the few areas of shade for thermoregulation (Rylander 1972, Johnson and Guthery 1988, Wolf and Walsberg 1996). As facultative heterotrophs roadrunners use shade's cooler microclimates to economize their energy resources. In these areas roadrunners will raise their internal temperature to maximize heat loss and minimize evaporative water loss (Rylander 1972, Cook 1997). Additionally, radiative heat stored in the rocks during the day can be utilized to warm roadrunners after sunset.

Rock was largely measured on the ridge top and slope. Rock offers open-space movement and an optimal location for radiative re-warming during winter and after

nighttime torpor (Cook 1997). In turn, these same locations can be used for hunting sunning prey. Finally, rocky outcrops on the tops of the ridge were often used by the roadrunners as an elevated position from which to view prey or threats below.

This model demonstrates the complexities of brush management to conserve, create, or improve habitat. When managing for roadrunners, a land manager must be conscious in maintaining patches of dense shrub for roadrunner protection, nesting, and thermoregulation. Managing roadrunner habitat in this manner may also benefit overall biodiversity as studies have found higher species richness in arid regions that include patches of shrub rather than strictly open grassland (Whitford 1997, Lloyd et al. 1998, Pidgeon et al. 2001, Bock and Block 2005).

Management Implications

This work gives land managers insight into the land use and preferences of roadrunners in this region of west Texas. Results from this study should be applied with caution in areas with different plant communities and topographic relief. More research would be necessary in different populations to determine if the land use and preferences are maintained.

CHAPTER IV

NEST SITE SELECTION PREDICTION MODEL

Introduction

Nest site characteristics can influence the quality and number of young (Martin and Roper 1988) and understanding the greater roadrunner's (*Geococcyx californianus*; here after roadrunner) nesting behavior and the selection of nest sites is critically important to their maintenance and reproductive success (Filliater et al. 1994, Maxon 2005). It is still unknown what prompts a roadrunner to choose a particular nest site (Maxon 2005). Previous studies describe the nest tree species as well as nest height from the ground (Ohmart 1973, Folse 1974, Meinzer 1993, Hughes 1996, Maxon 2005, Payne et al. 2005) but nest site selection is a balance of both site specific structural attributes and landscape characteristics (Martin and Roper 1988). The significance and magnitude of either for the roadrunner remains unknown (Maxon 2005).

The goal of this study was to understand the roadrunner's nest site selection in the context of topographic and vegetative features. Greater understanding of the roadrunner's nesting ecology can then be used to insure proper management and preservation of nesting habitat (Gregg et al. 1994, DeLong et al. 1995, Kolada et al. 2009).

Methods

Data were collected from May 2006 to October 2009 at the 3790-ha Smith-Walker Research Ranch (34° 02'16" N, 99°15'10" E) and surrounding private lands in

the Red Rolling Plains ecoregion of Wilbarger County, Texas (Gould 1975). Vegetation in this area included honey mesquite (*Prosopis glandulosa*), lote bush (*Ziziphus obtusifolia*), hackberry (*Celtis occidentalis*), cat-claw acacia (*Acacia greggii*), tracts of agricultural winter wheat, tame pasture for grazing cattle (6 to 8-ha per animal), and natural non-vegetated areas (Kelley et al. 2011).

I captured roadrunners using three methods. The first method was a modified bal-chatri trap (Berger and Mueller 1959, Lake et al. 2002, Vilella and Hengstenberg 2006) that consisted of a caged mouse (*Mus musculus*) surrounded by monofilament nooses on plywood boards that were nailed into the ground. These adjustments were implemented to address the roadrunner's unique ground-level hunting style (Kelley et al. 2011). The second technique was a traditional box trap with a caged mouse as bait (Vehrencamp and Halpenny 1981, Bub 1991, Kelley et al. 2011).

Roadrunners were measured with the help of a field assistant who restrained the bird by grasping its torso and holding down the wings. I then measured the roadrunners for mass, tarsus length, bill depth, bill width, bill tip to nearest dorsal feathers, bill tip to base of bill, bill tip to commissure, bill tip to nostril, and bill tip to the back of the head to the nearest 0.1-mm or 1-g, as appropriate. Both the bill width and bill depth were measured at the leading edge of the nostril. I then removed downy feathers for sex verification through PCR DNA analysis following the methods of Santamaria et al. (2010). Finally, birds were fitted with a 10-g back-pack style radio-transmitter and were then immediately released at the capture site without any apparent changes in behavior.

I relocated roadrunners 2-4 times per week via triangulation of compass bearings from 3-5 distant positions. Bird locations were calculated from compass bearings with the program LOCATE III (Nams 2006) utilizing the maximum likelihood estimator and estimated standard deviation settings.

Incubation was determined to have occurred when bird locations did not change over the course of several days. This was then confirmed through a search during incubation or shortly after hatching. Effort was made to locate active nests of unmarked birds by slowly searching areas with multiple observers where pairs of unmarked birds were seen. Nests were also located opportunistically during field work and in the fall when leaves were shed and nests were more visible. Nest status (used, unknown) were based on the presence of feathers in the nest bowl or on the ground around the nest tree and rarely with un-hatched eggs in the nest. Nest locations were recorded and later measured for vegetation structure within a 20-m radius of the nest tree after fledging.

An equal number of nest and random sites were examined. Random points were determined using a random number generator and were stratified to include only those cover types with woody vegetation as bare ground and pasture are known to be inappropriate for roadrunner nesting. The nearest tree or shrub closest to the random site was measured for vegetative structure in the same fashion as actual nest sites. Distance and direction were determined using the distance tool in Hawth's tool application (Beyer 2004).

Sites were examined and measured for the following variables: tree species (mesquite, lote bush, hackberry, mixed motte, other), tree height (m), tree growth habit

(single stem, multi-stem), number of stems, main nest branch (vertical, horizontal) and tree shape (round, oval, umbrella, large and sprawling, normal upright). Using a 20-m line intercept in the four compass directions, shrub species canopy cover was determined by species (mesquite, lote, hackberry, other) and in total. Shrub species richness was determined through a count of different species within a 20-m. radius. Shrub density was then determined by dividing the total number of shrubs within the 20-m radius (mesquite, lote, hackberry, other, total) by the area sampled (Density = $n/2\pi[20]^2$). Finally, the nearest type of edge was determined (paved road, other road, topographical change, brush line, mechanical brush clearing, other) and recorded. Nest sites were further examined and measured for fate of nest (success, failure, abandoned, unknown), clutch size, diameter at nest height (cm), nest height from ground (m), nest height from top (m), and nest distance to lateral edge (m).

Continuous data were tested for differences of means between random and non-random sites using a two-sample t-test or the non-parametric Wilcoxon signed-rank test as dictated by normality testing. Categorical variables at random and confirmed nest sites were similarly compared with Pearson's Chi-squared test. Features exclusive to the nest sites (e.g. fate, clutch size, etc.) were described using means and confidence intervals.

Seventy percent of the data (n = 70) were used to build a nominal logistic regression model through evaluation of the goodness-of-fit, lack of fit, AICc, AIC differences (Δ_i), and Akaike weights (ω_i; Burnham and Anderson 2001), R^2 and the area

under the receiver operating characteristics curve (AUC). Odds ratios for the model's parameter estimates were reported.

I then cross validated the model using the remaining 30% of the data (n = 30) reporting whole model significance, goodness of fit, and AUC. All statistical testing was performed in JMP 9 (SAS Institute 2007) at a significance level of $\alpha = 0.05$.

Results

Fifty roadrunner nesting and 50 random locations were examined. Of the 50 roadrunner nests, 14% were confirmed successful (n = 7), 26% failed (n = 13), 4% were abandoned (n = 2), and 56% of the nests had unknown fates (n = 28). Of the 22 nests of known fates, clutch sizes ranged from 0 to 7 eggs and averaged 3.14 eggs (CI = 2.06, 4.22). Nests averaged 2.26-m from the ground (CI = 2.01, 2.50), 2.25-m from the top of the tree (CI = 1.93, 2.75) and 1.69-m from the lateral edge (CI = 1.43, 1.95). Fifty two percent were on single stem shrubs (n = 26) while 48% were in multi-stem shrubs (n = 24). The diameter of the nesting tree at the height of the nest averaged 7.46-cm (CI = 4.14, 10.79). Forty six percent of nests (n = 23) were found in honey mesquite, 6% percent (n = 3) were found in lote bush, 34% were in hackberry (n = 17), 12% were in mixed mottes (n = 6), and 2% were found in other tree or shrub species (soapberry; n = 1).

The statistics for continuous variables measured at both random and actual nest sites and the results of their corresponding comparison of means tests are summarized in Table 6. The statistics for the categorical data measured at both random and actual nest sites and their corresponding results from differences in proportions testing are

Table 6. T-test and Wilcoxon signed ranked test results of random versus actual location nest site selection means.

Variable	Random mean (CI)	Nest site mean (CI)	t-test	Wilcoxon Signed Rank
Tree Height	4.75 (4.41,5.09)	4.389 (3.91,4.87)	t = 2.1405; P = 0.0373	
Total density	838.947 (768.87, 909.02)	757.56 (642.03,873.09)		T= 210.5; P = 0.0409
Mesquite density	705.697 (643.82,767.57)	511.01 (423.29,598.73)	t = 6.3232; P < 0.0001	
Hackberry Density	6.356 (1.65,11.06)	13.69 (3.48,23.91)		T = -502.5; P < 0.0001
Other density	21.95 (9.57,34.34)	75.73 (7.43,144.03)		T = -548.5; P < 0.0001
Total CC	56.96 (51.87,62.05)	65.90 (45.49,86.31)		T = -313.5; P = 0.0017
Mesquite CC	48.45 (43.57,53.33)	43.5 (37.15,49.85)	t = 2.0390; P = 0.0469	
Lote CC	4.05 (2.27,5.54)	7.03 (4.53,9.52)		T = -373.5; P = 0.0001
Hackberry CC	3.17 (0.59, 05.75)	4.86 (2.41,7.31)		T = -390.5; P < 0.0001
Other CC	1.76 (-0.27,3.79)	1.42 (0.21,2.64)		T = -474.5; P < 0.0001
Nest dist from edge	25.706 (21.80,29.61)	20.05 (25.28,14.83)		T = 245.5; P = 0.0162

Table 7. Comparison of mean vegetative characteristics at greater roadrunner nest sites and random sites in north central Texas, 2006-2009.

Variable	Random	Nest site	Pearson's χ^2
Nesting Tree Species			
Mesquite	0.80	0.46	$\chi^2 = 36.13$; $P < 0.0001$
Lote bush	0.04	0.06	$\chi^2 = 0.52$; $P = 0.4705$
Hackberry	0.14	0.34	$\chi^2 = 16.61$; $P < 0.0001$
Mixed motte	0.02	0.12	$\chi^2 = 25.51$; $P < 0.0001$
Other [A]	0.00	0.02	
Type of Edge			
Single stem	0.30	0.52	$\chi^2 = 11.52$; $P = 0.0007$
Multi-stem	0.70	0.48	$\chi^2 = 11.52$; $P = 0.0007$
Nest Tree Shape			
Round	0.08	0.08	$\chi^2 = 0.00$; $P = 1.0000$
Oval	0.02	0.16	$\chi^2 = 50.00$; $P < 0.0001$
Umbrella [A]	0.00	0.10	$\chi^2 =$ ** ; $P < 0.0001$
Old-large sprawling	0.30	0.14	$\chi^2 = 6.10$; $P = 0.0136$
Normal upright	0.60	0.52	$\chi^2 = 1.33$; $P = 0.2482$
Type of Edge			
Paved road	0.00	0.00	$\chi^2 = 0.00$; $P < 0.0001$
Other road	0.74	0.64	$\chi^2 = 2.60$; $P = 0.1069$
Topographic change	0.04	0.26	$\chi^2 = 63.02$; $P < 0.0001$
Brush line	0.08	0.00	$\chi^2 = 0.00$; $P < 0.0001$
Roller chopped	0.00	0.00	$\chi^2 = 0.00$; $P < 0.0001$
Other	0.14	0.10	$\chi^2 = 0.66$; $P = 0.4200$

[A] Because a zero value was entered for the hypothesized probability and the estimated probability is greater than zero the p-value for the Chi-squared test is zero.

Table 8. Three strongest nest site selection models and their associated statistics including AICc, AIC differences, Akaike weights, R^2, and AUC; (*N*) >0 predicts actual nest site locations, (*N*) <0 predicts random or non-nest sites.

Equation	AICc	Δ_i	ω_i	AUC	R^2
$(N_1) = 3.94 - 1.15(MNT) + 2.04(OTS) - 0.01(MD) + 0.05(MCC) + 1.36(TE)$	71.83	0.00	0.862	0.89	0.40
$(N_2) = 1.55 - 1.15(MNT) + 1.38(OTS) + 0.02(MCC) + 1.15\ (TE)$	83.71	11.88	0.002	0.83	0.25
$(N_3) = 4.74 - 0.89(MNT) + 1.58(OTS) - 0.004(MD) + 1.37(TE)$	75.53	3.70	0.116	0.86	0.33

Table 9. Odds Ratios and confidence intervals for the parameter estimates of the N_3 nest site selection model.

Variable	Odds Ratio	Odds Ratio CI
Mesquite Nesting Tree	0.168	(0.043, 0.577)
Oval Tree Shape	23.718	(2.694, 549.576)
Mesquite Density	0.0171	(0.001, 0.265)
Topographic Edge	15.405	(2.438, 153.221)

summarized in Table 7.

The top three models are summarized in Table 8. All three models' whole model tests were found significant with no lack of fit. While the first nest site model (N_1) had the largest predictive power (AUC) but further testing found mesquite density and mesquite canopy cover to be significantly correlated (ρ = 0.4807; CI = 0.2770, 0.6431; P < 0.0001). The second model (N_2) was then run without mesquite density and the third (N_3) without mesquite canopy cover. N_3 was determined to be the stronger of the two models because N_2 has a smaller AUC, larger AICc, larger Δ_2, and smaller ω_2. Odds ratios for the chosen model (N_3; Table 9) indicate the importance of shrub diversity as nest sites had lower odds of a mesquite nesting tree and higher mesquite density. Additionally there were higher odds of topographic edge and oval tree shape in nesting sites.

The validation of the chosen model using the remaining 30% of the data still had a significant whole model test (χ^2 = 15.8919, P = 0.0032), showed no lack of fit (χ^2 = 25.6969, P = 0.4239), and had an AUC measuring 0.8667.

Discussion

Previous estimates have focused on the height of the nest and species of the nesting tree. A majority of the nests in this study were found in mesquite as is typical of semi-arid regions of Texas (Folse 1974, Maxon 2005). Other studies in more western arid regions generally found nests in different species of cactus (Ohmart 1973, Maxon 2005). Consistent with previous studies, I found nest heights ranging from 1-3 m (Ohmart 1973, Folse 1974, Meinzer 1993, Hughes 1996, Maxon 2005) and nests to be

equally situated from the top and bottom of the tree (Folse 1974, Hughes 1996 unpublished).

Many of the nests in this study are of unknown fate because of the difficultly spotting roadrunners (Folse 1974, Vehrencamp and Halpenny 1981, Bolger et al. 1991, Kelley et al. 2011) and were found after active use by the bird. I do not believe this to be a detriment to the study as roadrunner numbers in this region appear to be stable.

The logistic regression model and validation statistics were both strong and lend credibility to the use in this area. The accuracy (86%) was larger than comparable published studies which ranged from 70 to 84 percent (Li and Martin 1991, Bisson and Stutchbury 2000, Lusk et al. 2003, Lusk et al. 2006). The resulting odds ratios emphasize both the importance of cover for thermal regulation (Ohmart 1973) and protection from predators (Filliater et al. 1994, Maxon 2005) as well as edges for efficient hunting and transportation. They also describe nest sites as less likely to occur in areas of higher mesquite density and in a mesquite nesting tree. Both these predictors and the increased likelihood of nearby topographic edges (mostly riparian edges) allude to the importance of shrub diversity given mesquite's large presence and potential for expansion in Texas (Ansley et al. 2001).

The repercussions of these findings on roadrunner nest site management are complex. In this area, responsible brush management is an important tool in maintaining nest sites through the preservation of shrub diversity, clearings, and edges. The technique and frequency must be tailored for roadrunner use. For example, both clear cutting and top removal would be inappropriate for the study site as clear cutting

completely eliminates nesting substrate and top removal results in smaller multi-stem plants.

Inappropriate brush management could potentially impact roadrunners beyond the nesting seasons as these shrubs could be further used for temperature regulation and nocturnal roosts (Rylander 1972, Hughes 1996). Additionally, the management of habitat for roadrunner nesting is likely indicative of the needs of multiple arid land songbirds as nests for painted buntings (*Passerina ciris*), northern orioles (*Icterus galbula*), and yellow-billed cuckoos (*Coccyzus americanus*) were also found in the area.

Management Implications

This study will make it possible for land managers to anticipate and manage roadrunner nesting habitat in this region. Other areas of the roadrunner range with different plant communities and topography should apply these results with caution. Though the concepts of shrub diversity and nearby edge could easily be applied to roadrunners in different populations, further research is needed to insure land managers understand any region specific nesting preferences.

CHAPTER V

MOROPHOMETRIC SEX IDENTIFICATION MODEL

Introduction

Accurate sexual identification is important in understanding common questions of community ecology. These include sex ratios in a breeding population, differential mortality, behavioral studies (e.g., male/female incubation behavior), differential habitat selection, and sex specific demographics (Iko et al. 2004, Gill and Vonhof 2006, Wallace et al. 2008). These topics are difficult to study in the greater roadrunner (*Geococcyx californianus*; here after roadrunner) because of their sexually monomorphic plumage. This lack of information makes roadrunner management difficult and only speculative in practice

Previous studies have successfully sexed roadrunners using copulatory behavior (Whitson 1976), dissection (Ohmart 1973), and PCR-based DNA analysis (Santamaria et al. 2010) but failed in describing an easy, unambiguous, and field-relevant methodology. It was proposed that the sexes displayed differences in the coloration of the post orbital apterium (Folse and Arnold 1978) but this was later found to be unreliable (Meinzer 1993).

The goal of my study was to find a field-relevant methodology for identifying male and female roadrunner in the hand at point of capture. To this end, I used morphological measurements taken from live captured birds in which sex was identified using DNA extracted from feathers and from skins in university and museum vertebrate

collections. This data was used to build a reliable logistic regression model with a large sample of birds from across their range. This method of morphometric sex identification is easy, inexpensive, non-invasive (Wallace et al. 2008) and has been successfully used with bird species across very different ecosystems (Rodriguez et al. 1996, Gill and Vonhof 2006, Herring et al. 2008).

Methods

Live captured, recently deceased remains, and museum roadrunner specimens were measured similarly for the purposes of this study. Museum roadrunner skins were utilized to increase the sample size and include roadrunners from across their range (Table 10).

It was assumed that specimen shrinkage was minimal over time and consistent between the sexes such that any sex specific difference was maintained. Further, it was assumed that museum preparations were consistent between collections and measurements and sex were correctly identified and recorded. Finally, three road-kill roadrunners were measured and used in the analysis as damage was minimal and sex could be identified with an internal exam or PCR.

Live specimens and recently deceased specimens were measured from birds on or around the Rolling Plains Quail Research Ranch (32°02’16” N, 100° 32’ 50” E) in the Fisher County, Texas. Roadrunners were captured using three methods. One method was a modified bal-chatri trap (Berger and Mueller 1959, Lake et al. 2002, Vilella and Hengstenberg 2006) that consisted of a caged mouse (*Mus musculus*) surrounded by

Table 10: Sources of non-living roadrunner samples and their contributions to the sample size.

Roadrunner Skin Locations	Contribution
Sam Houston State University Vertebrate Museum	5
Museum of Southwestern Biology at the University of New Mexico	60
New Mexico Museum of Natural History	3
Sam Noble Museum at the University of Oklahoma	32
Texas Cooperative Wildlife Collections at Texas A&M University	32
Angelo State University Natural History Collections	10
Mayborn Museum at Baylor University	10
Road kill	3
Rob and Bessie Welder Wildlife Foundation	16
Texas Tech	10
Natural Science Research Laboratory at the Museum of Texas Tech University	8
California Collections	79
Smithsonian Institution National Museum of Natural History	92

monofilament nooses attached to plywood boards that were nailed into the ground. These adjustments were implemented to address the roadrunner's unique ground-level hunting style (Kelley et al. 2011). The second method was a large box trap with a caged mouse as bate (Vehrencamp and Halpenny 1981, Bub 1991, Kelley et al. 2011). Finally, a small number of birds were successfully hand captured in the field. These birds were newly fledged juveniles or adults cornered by a fence or dense shrub.

The measurements, largely shown in figure 1, were determined with the help of a field assistant who restrained the roadrunner by grasping its torso and holding down the wings. I measured the roadrunners mass, tarsus length (H), bill depth (F), bill width (G), bill tip to nearest dorsal feathers (D), bill tip to base of bill (C), bill tip to commissure (B), bill tip to nostril (E), and bill tip to the back of the head (A) to the nearest 0.1-mm or 1-g, as appropriate. Both the bill width and bill depth were measured at the leading edge of the nostril. I then removed downy feathers for sex verification through PCR DNA analysis following the methods of Santamaria et al. (2010). Finally, birds were fitted with a 10-g back-pack style radio-transmitter and immediately released at the capture site without any apparent changes in behavior

I compared the means of male vs. female measurements using either the parametric t-test or non-parametric signed rank according to the results of normality testing. Two techniques for morphometric sex identification have been successfully used: logistic regression (Rodriguez et al. 1996, Gill and Vonhof 2006, Wallace et al. 2008) and discriminate analysis

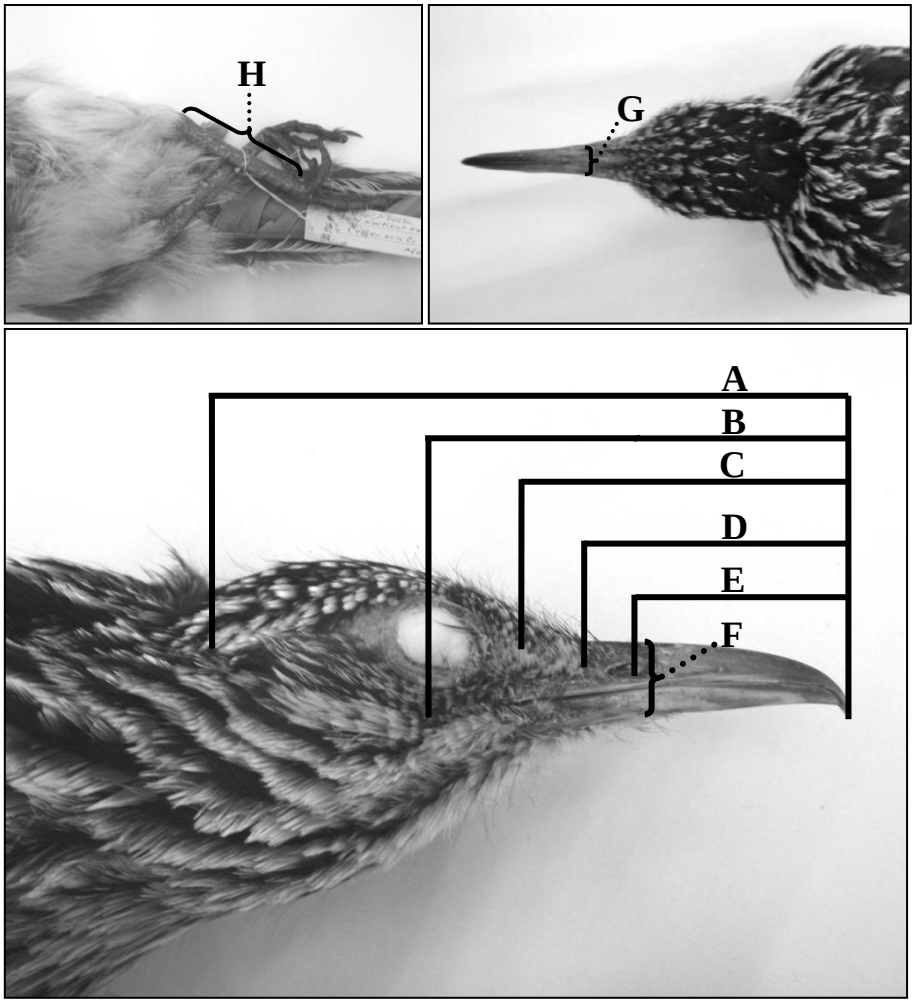

Figure 1: Diagram of roadrunner morphometric sex identification measurements.

(Shephard et al. 2004, Hermosell et al. 2007, Herring et al. 2008). My data did not exhibit a normal distribution or homoscedasticity for all predictive variables so a logistic regression was more appropriate. Eight percent of the data (n = 284) was randomly chosen and used as a training data set to build the model. The strongest model was chosen through evaluation of the area under the receiver operating curve (AUC), whole model testing, goodness of fit testing, AICc, AIC differences (Δ_i), and Akaike weights (ω_i; Burnham and Anderson 2001). The chosen model's odds ratios were then reported.

The model was then validated with a validation data set comprising the remaining 20% (n= 72). The data were then run using the chosen model's variables and the results for the whole model test, goodness of fit test, and AUC were reported. JMP 9 (SAS Institute 2007) and a significance level of $\alpha = 0.05$ was used for all statistical analysis.

Results

I recorded measurements on 359 roadrunners. Females were under-represented in all statistical comparisons (Table 11). Sample sizes differed for several morphological variables due to damage and normal wear of older specimens (Table 12). For example, those skins with missing or badly damaged legs were not measured for tarsus length. The results of variable mean testing for differences between males and females are summarized in Table 12.

The strongest three models were chosen based on the significance of the whole model test, lack of fit test, and AUC (Table 13). The first model (S_1) had a significant

Table 11. Male/Female distribution of total, training, and validation data sets.

	Male and female	Male *n* = (%)	Female *n* = (%)
Total data set	359	218 (60.7)	141 (39.3)
Training data set (80 %)	287	172 (59.9)	115 (40.1)
Validation data set (20 %)	72	46 (63.9)	26 (36.1)

Table 12. T-test and Wilcoxon signed rank test results of significantly different male vs. female mean morphometric measurements.

Variable	Female mean (CI)	Male mean (CI)	t-test	WSR
Tarsus length (n = 350)	57.31 (56.50, 58.13)	58.85 (58.20, 59.50)		T = -1655.5; P = 0.0001
Bill tip to feathers (n = 346)	42.73 (42.01, 43.47)	45.08 (44.53, 45.63)	t = -6.36; P < 0.0001	
Bill tip to base (TtB; n = 355)	51.51(50.71, 52.31)	54.48 (53.90, 55.07)		T = -2940.5; P < 0.0001
Bill tip to nostril (n = 355)	33.37 (32.86, 33.87)	35.35 (35.00, 35.70)		T = -3201.5; P < 0.0001
Bill tip to back of head (BoH; n = 238)	90.10 (88.99, 91.20)	93.06 (92.24, 93.87)	t = -5.32; P < 0.0001	
Bill tip to commissure (n = 347)	60.62 (59.80, 61.45)	63.42 (62.57, 64.26)		T = -2526.0; P < 0.0001
Bill depth (BD; n = 358)	11.49 (11.33, 11.65)	12.65 (12.51, 12.78)		T = -4458.0; P < 0.0001
Bill width (n = 358)	9.55 (9.41, 9.68)	10.24 (10.12, 10.36)		T = -3771.5; P < 0.0001

Table 13. Three strongest roadrunner logistic regression sexing models using the training data set.

Equation	AICc	Δ_i	ω_i	AUC	R^2
$(S_1) = -13.85 + 0.89(BD) + 0.07(TtB)$	321.84	99.12	0.00	0.792	0.17
$(S_2) = -11.61 + 1.00(BD)$	328.34	105.62	0.00	0.787	0.16
$(S_3) = -13.55 + 0.05(BoH) + 0.79(BD)$	222.72	0.00	1.00	0.766	0.15

Table 14. Odds ratios (male versus female) and confidence intervals of the chosen model's (S_3) parameter estimates.

	Odds Ratio (CI)
Bill tip to back of head	4.607 (0.563, 39.703)
Bill depth	138.76 (15.544, 1518.597)

Table 15. After measuring the roadrunner to be sexed, enter the values into the equation (S_3). Values of (S) >0 are female, while <0 are male. A researcher using this model must remember that there is an error rate associated with this model and, if necessary, sex can be confirmed through PCR. Correct and incorrect model result examples are below.

	BoH (mm)	BD (mm)	Equation Results	Model Sex Identification	PCR Results
Correctly ID	76.95	9.16	-2.47	Male	Male
Correctly ID	88.37	13.05	1.17	Female	Female
Incorrectly ID	92.32	10.30	-0.80	Male	Female
Incorrectly ID	89.36	11.62	0.10	Female	Male

whole model test ($\chi^2 = 66.03$, $P < 0.0001$) but did show a lack of fit ($\chi^2 = 315.75$, $P = 0.0030$). The variable of bill tip to base (TtB) was removed and the resulting model (S_2) was tested. Bill depth (BD) and whole model test were significant but it maintained a lack of fit ($\chi^2 = 172.49$, $P < 0.0001$). The final model (S_3) included bill depth and bill tip to the back of the head and had an AUC similar to previous models, a significant whole model test ($\chi^2 = 42.729$, $P < 0.0001$), and showed no lack of fit ($\chi^2 = 216.59$, $P = 0.0750$). This choice in models was then confirmed with differences in AICc ($\Delta_i = 0$) and Akaike weights ($\omega_i = 1.00$; Table 10). The odds ratios of the two model variables were calculated (Table 14) and showed both bill depth and bill tip to the back of the head were larger in males.

Validation of the (S_3) model with the remaining 20% of the data still had a significant whole model test ($\chi^2 = 41.18$, $P < 0.0001$), showed no lack of fit ($\chi^2 = 17.40$, $P = 0.9997$), and an AUC of 0.9720. Instructions on use of the model in the field are presented in Table 15.

Discussion

Roadrunners for this study included specimens from across their range though most were from Texas, Arizona and New Mexico. The true distribution of locations was difficult to quantify given inconsistent availability of location data in museum records. The accuracy of this morphometric sexing model is promising given the training and validation data sets' AUC. Additionally, because of the manner in which bill depth and bill tip to the back of the head are measured, there is less probability of variation between investigators. Unlike tarsus length or bill tip to nostril, these two measurements

allow calipers to grip bony structure so there is no need for interpretation of a true beginning or end.

Similar biometric studies in birds have degrees of accuracy ranging from 15 - 99.7% with 60% reporting accuracies greater than 90% (Hernandez 2011). The accuracy of this model (77%) is likely lower than the majority sampled in this review in large part because this model included roadrunners from across the entirety of their range rather than a single population.

I was only able to measure birds from across their range through the inclusion of museum skins. Given the high degree of difficulty in trapping roadrunner (Folse 1974, Vehrencamp and Halpenny 1981, Bolger et al. 1991, Kelley et al. 2011), this study could not have realistically been completed otherwise. The inclusion of museum specimens can potentially introduce error through damage or shrinkage (Jenni and Winkler 1989, Winker 1993;1996) but I am confident that shrinkage was not a sizable source of variation in this model as I did not include measurements of damaged portions and measurements were limited by bony structures, rather than soft tissue.

My intention for this model was to sex adults only as juveniles would complicate the model and likely effect the accuracy (Pyle 1997). The difficulty with this is that past 85 days, young of the year roadrunners are difficult to identify as their size, plumage and black mouths appear indistinguishable from adults (Pyle 1997, Maxon 2005). In addition, other common methods of aging, such as percent skull ossification or wing chord length, were not uniformly available for all specimens. I therefore determined adulthood through visual comparisons of size, plumage condition, mouth color, month of

capture or death, and behavior when available. The coloration of the roadrunner's plumage and iris are thought to be different between juvenile and adults but no empirical evaluation can attest to the reliability (Pyle 1997).

It is worth nothing that all three models contained bill depth. Given the relative stability of the statistics, researchers may find the model with only bill depth (S_2) more convenient to implement despite its lack of fit.

Management Implications

This model offers an easy, inexpensive, and reliable model to predict roadrunner sex in hand at the point of capture. Though PCR analysis would be a valuable tool for borderline individuals, this model will make future roadrunner studies easier and less reliant on expensive equipment.

CHAPTER VI

CONCLUSIONS

The first portion of this study was conducted in Fisher County, Texas. I documented a mean roadrunner nesting range (43.01-ha) similar to previous non-telemetry home range estimates (Bryant 1916, Calder and Schmidt Nielsen 1967, Folse 1974) and mean 50% core utilization distribution (11.88-ha) and overlap index (33.05 %) similar to the Kelly et al. (2011) telemetry study in north central Texas. I expected the nesting range estimate to be more similar to Kelly et al.'s (2011) telemetry study as comparable methods were used. The difference is likely attributed to both the completion of my study exclusively during the nesting season as well as the considerable use of ridges by the Fisher County population. Ridges offer additional vertical area not accounted for in conventional home range estimates (Greenberg and McClintock 2008).

Habitat selection index calculations confirm roadrunner preference for ridge along with grassland habitat. Previous studies reported a preference for shrubs and avoidance of grasslands (Kelley et al. 2011) but this difference is likely an artifact of methodology. My study utilized an aerial image of sufficient detail to differentiate grassland habitat between individual shrubs therefore creating results at a finer scale. My study also found roadrunners avoided bare ground and flatland habitats. Both of these habitats supported very few shrubs making it difficult for roadrunners to avoid predators and escape direct sunlight during the heat of the day.

A point location study using the same data found percent rock and litter the best predictors of roadrunner land use. Rock offers open area for hunting and transportation

and was largely associated with ridge habitat (already shown to be preferred). Litter alludes to the area under dense shrubs. Shrubs are a known nesting substrate and roosting location for roadrunners to thermoregulate. Habitat selection calculations showed shrubs used only proportionally to availability but this model demonstrates that shrubs still compromise an important component of the plant assemblage.

The sexing study consisted of the roadrunner measurements from Fisher County, Texas as well as museum specimens from across their range for the development of a sex identification model. The most reliable model included the parameter estimates of bill depth and bill tip to the back of the head which were both found to be larger in males. This model should provide an easy, inexpensive, accurate, and field-relevant methodology for sex identification of roadrunners in the hand at the point of capture.

The nest site study was performed in Wilbarger County, Texas and sought to find the significant characteristics in roadrunner nest sites. The variables included mesquite nesting tree, oval tree shape, mesquite density, and topographic edge were found to be the best in distinguishing nest sites from random sites. Most notably, the odds ratios of mesquite nesting tree (0.168) and mesquite density (0.0171) demonstrate the need for shrub diversity in nest sites as the odds of finding either were higher in random sites.

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